Oxygen Extraction from Regolith Using Ionic Liquids

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Introduction

Fabricating materials while in space is a key component to affordable, long-duration manned space travel. Oxygen, which is necessary for propulsion and life support, is abundant in the form of oxides present in various extra-terrestrial regoliths. Using ionic liquids to extract this oxygen (and metals) has been proven in the laboratory as a promising technique.

Ionic liquids, which have a low vapor pressure and are capable of melting below 100°C, allow the operating temperature of the procedure to be lowered from 1600°C (previous methods) to 200°C.

The extraction process using ionic liquids would be performed as follows:

- ❖ Solubilization of regolith at 200°C (or lower) producing water vapor and metal ions

$$\textit{Regolith (Metal Oxides) + Ionic Liquid} \rightarrow H_2O_{(v)} + \textit{Metal Ions}$$

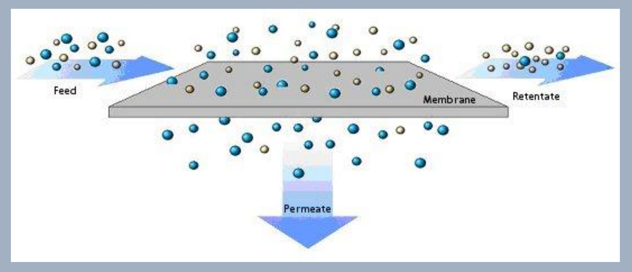
- ❖ Distillation of water vapor from reaction mixture followed by condensation of water vapor
- ❖ Electrolysis of liquid water to produce O_2 (collected) and H_2(regeneration of ionic liquid)

$$2H_2O \xrightarrow[\text{ionic liquid}]{e^-} 2H_2 + O_2$$

Performing this process while in a low-gravity environment can be problematic since some steps rely heavily on buoyancy for phase separation. For phase separation in space, an alternate method must be considered.

Methods

Pervaporation is a separation process that is independent of the buoyancy of a substance. Instead, it relies on a selective membrane material and an applied pressure differential across the membrane.

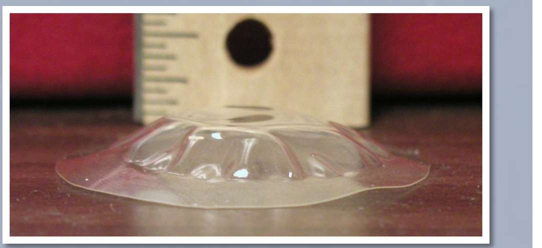


Basic concept of pervaporation

Four tests were performed on a sulfonated Teflon membrane (thickness 183 µm) to determine compatibility with ionic liquids and applicability to the oxygen extraction process. Test 1 and Test 2 evaluate if it is necessary to have constant stirring; Test 3 evaluates the process at an elevated operating temperature; and Test 4 evaluates the process operating for extended periods of time. All tests were performed with a 20mL sample of 30% aqueous ionic liquid.

Results and Discussion

The testing apparatus was verified prior to testing with ionic liquids. 100 mL of distilled water was placed into the top of the funnel and the vacuum pump turned on to 4.5 Torr. 5 mL of water was collected in 4 hours (water flux: 1225.8 g/m²hr) and 0.0646g of water was absorbed by the membrane. These results demonstrate that the system works as needed. They also demonstrate that the membrane must be pre-saturated to enable quantitative measurement.



Membrane after pre-treatment

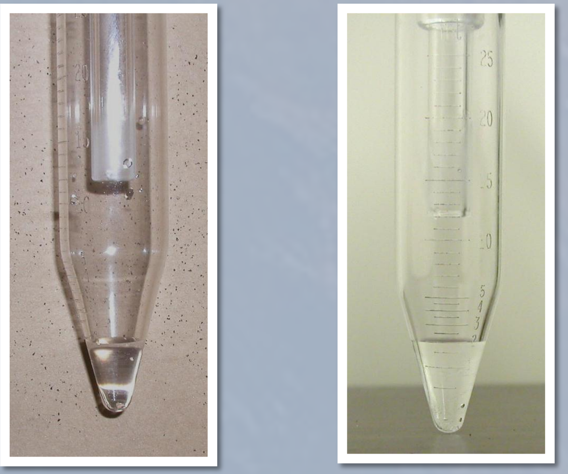
Pervaporation Testing Apparatus (Final Design)

Other apparatus parts (not in picture):

- ❖ Mechanical vacuum pump
- ❖ Neoprene tubing
- ❖ Helium purge
- ❖ Membrane contact area: 1017.88mm²

Test 1 and Test 2 began the series of tests on 30% aqueous ionic liquid. These two tests were performed at 20°C for 6.5 hours.

- ❖ Test 1 (no stirring) produced a water flux of 150.90 g/m²h through the membrane. This is much less than the water flux of pure water. Test 1 also produced a significant drop in pressure (ΔP = -200 mTorr). These results suggest a build up of ionic liquid on one side of the membrane, limiting water transport.
- ❖ Test 2 (stirring) produced a water flux about three times higher than Test 1 (water flux = 301.74 g/m²h). Also the change in pressure was minimal (ΔP = 33 mTorr).
- ❖ Conclusion: A stirring mechanism is necessary.



Left: Test 1 - 1 mL H_2O collected, no stirring

Right: Test 2 – 2 mL H_2O collected, with stirring

Test 3 was conducted at 50°C for 6.5 hours using a stirring mechanism.

- ❖ Heat in combination with stirring increased the water flux (452.52 g/m²h)
- ❖ 2.5 mL of liquid was lost during the process, possibly due to evaporation
- ❖ Condensation formed on funnel
- ❖ Conclusion: This separation process performs well under elevated temperatures

3 mL H2O in collection tube

Test 4 was conducted at 20° for 78.5 hours (3 days, 6.5 hours).

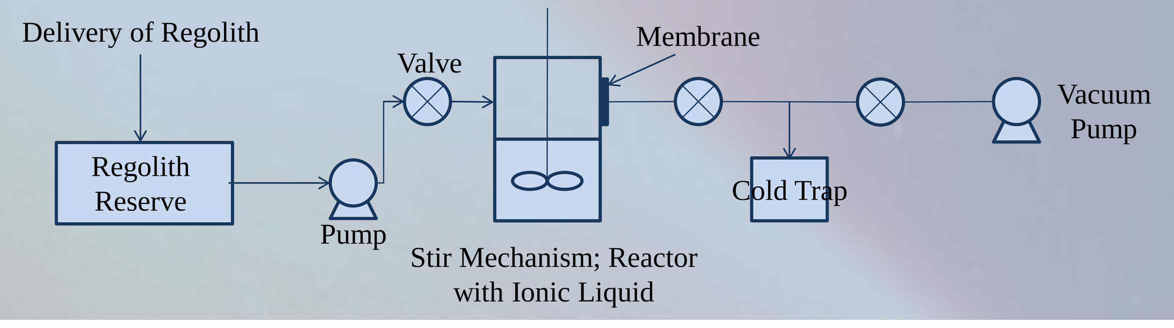
Membrane after 78.5 hour test (test 4)

- ❖ Membrane was not swollen. This means the pre-treatment water started being pulled from the membrane; therefore, water flux was not calculated. Unsure when the process switched from pulling water from the ionic liquid to pulling from the membrane
- ❖ 10 mL liquid left in funnel; more viscous than starting liquid
- ❖ Conclusion: Membrane is compatible with ionic liquid for extended period of time

Conclusions

This study confirmed that a sulfonated Teflon membrane could successfully separate water from an ionic liquid. A stirring mechanism must be used in order to avoid build up on one side of the membrane. The membrane is capable of handling the ionic liquid at elevated temperatures and extended time periods while performing pervaporation. These results suggest pervaporation could be a highly successful separation process to be used in oxygen (and metal) extraction from regolith. Due to the fact that pervaporation relies on surface energy and not buoyancy, this process could also be highly successful in a low-gravity environment.

Below is a basic schematic of the process flow diagram incorporating pervaporation. Once further studies are done, this schematic can be further refined and variable values determined.



Future Work

- ❖ Test pervaporation and the membrane during actual regolith (simulant) solubilization
- ❖ Examine the rest of the oxygen extraction process for problems that could results from low-gravity and determine solutions to these problems
- ❖ Further develop and refine process schematic so a model can be made and tested in a simulated low-gravity environment

References

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NASA Academy 2011 at Marshall Space Flight Center